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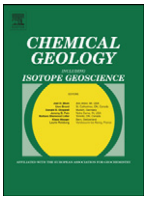

Evolution and origin of the Miocene intraplate basalts on the Aleppo Plateau, NW Syria

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ABSTRACT

The source of intraplate basalts has long been a controversial topic, particularly in continental settings where ambiguity increases because both crustal contamination and crystal fractionation may mask important source characteristics. We present geochemical data to constrain the source and the chemical evolution of the continental intraplate magmas from the Aleppo Plateau and vicinity, NW Syria. New ^{40}Ar/^{39}Ar ages, coupled with published ^{40}Ar/^{39}Ar and K–Ar ages, reveal two discrete Miocene volcanic phases, ~19–18 Ma (Phase 1) and ~13.5–12 Ma (Phase 2), in the studied area. New chemical and isotopic compositions [^{87}Sr/^{86}Sr = 0.7036–0.7051, εNd = +4.5 to +1.1 and $(^{187}\mathrm{Os}/^{188}\mathrm{Os})_t = 0.151–0.453$] of the lavas reflect the unequivocal influence of crustal assimilation and fractional crystallisation (AFC). Despite the effects of the AFC processes, there still appear to be some differences between the most-primitive, least contaminated magmas of the two volcanic phases, interpreted as a result of source heterogeneity. Whereas the Phase 1 lavas, with relatively high Si, low Ti and trace-element contents, are consistent with partial melting of a largely peridotitic mantle source, the origin of the Phase 2 lavas is more complicated. The latter are characterised by a source component depleted in Si and enriched in Ti, Fe, Ca, P, alkalis, light and middle rare earth elements (REEs) relative to heavy REEs and with sub-chondritic Th–(U)/Nb, Pb/Ce and Zr/Sm. They approach compositions of experimental melts of amphibole-rich metasomatic veins. The compositional variations among the most primitive Phase 2 lavas are difficult to reconcile with varying degrees of partial melting of either the metasomatic veins or peridotite, but could be explained if partial melts of both lithologies were variably mixed, a scenario that could be sensibly envisioned as ascending (peridotitic) plume/asthenosphere derived melts assimilating highly fusible metasomatic veins during their traverse through the lithosphere. This process can be loosely quantified by trace-element forward partial melting modelling that suggests mixing of up to 80% metasomatic melts derived from ~40% melting of amphibole-rich metasomatic veins (which themselves were inevitably compositionally and mineralogically heterogeneous) with 20% plume/asthenospheric melts derived from ~7% melting of a garnet peridotite. Within the compressional framework of northern Arabia, invocation of diapiric material reasonably accounts for the generation of the intraplate basalts in Syria. Derivation of the Phase 2 hybrid melts was probably triggered by lateral flow of this diapiric material beneath the lithosphere subsequent to its arrival, with the migrating flow-front controlling the locus of volcanism. The increase in degree of Si-undersaturation with time for the Phase 1 and Phase 2 lavas is best explained by decreasing temperatures of this flow-front that resulted in less melt contribution from the diapiric mantle while the amphibole-rich veins within the lithosphere continued to be easily fusible, although we cannot totally exclude the possibility that the Phase 2 volcanism tapped a vein-richer domain which formed subsequent to the Phase 1 volcanism.

1. Introduction

The continental lithosphere is thicker and compositionally more variable than its oceanic counterpart. As such, magmas generated in continental settings are potentially more susceptible to compositional modification via magma–lithosphere interaction during their ascent to the surface. This is supported by the wide range of chemical and

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isotopic compositions of continental intraplate basalts, of which some display compositions akin to oceanic basalts and others have signatures more typical of continental crust (e.g. Carlson, 1991). The latter is normally characterised by high large ion lithophile elements (LILEs, e.g. Rb) and "enriched" isotopic signatures (e.g. low εNd and high ^{87}Sr/^{86}Sr) that must reflect some contributions from the continental lithosphere traversed by the magmas (Hawkesworth et al., 1984; Baker et al., 1996a, 2000). Consequently, understanding magma genesis and its related geodynamics in continental settings is generally more difficult, and requires unravelling the complex evolutionary history (crystal fractionation and wall-rock assimilation) of the magmas during lithospheric mantle and crustal passage and storage.

In this contribution, we present and discuss the petrography, bulk-rock ^{40}Ar/^{39}Ar ages, chemical and Sr–Nd–Os isotopic data for continental basalts from the Miocene intraplate basaltic volcanic fields of Syria (Fig. 1). A subset of the samples was also analysed for platinum-group elements, which is reported and discussed elsewhere (Ma et al., in press). Some of the Syrian Miocene volcanic fields have been the subjects of previous studies, with the petrochemical data collected essentially at a reconnaissance level (Mouty et al., 1992; Sharkov et al., 1994; Lustrino and Sharkov, 2006). Recently, in a more detailed work, Krienitz et al. (2006, 2009) presented chemical and Sr–Nd–Pb isotopic data and proffered the idea of a significant degree of crustal assimilation (up to 25% upper crustal contamination) in the compositions of many of these basalts. However, this proposal has subsequently been criticised for underrating the effects of low-temperature alteration while overestimating the significance of crustal assimilation (Lustrino and Wilson, 2007). Therefore, the question of crustal assimilation has been left somewhat open.

It is the intention of this study to revisit this issue, opening a window to further explore the evolution and source characteristics of Syrian volcanism. Some samples were collected with the aim to represent both primitive and crustally-contaminated magmas, at previously sampled locations (e.g., Bulbul and Jabal El-Hass; Krienitz et al., 2006). Additional samples were collected from previously unstudied (or poorly studied) areas (e.g., Salamiyeh Plateau and Abou Ad-Dohour Plateau) to provide a better coverage of the Miocene volcanic rocks. Because the previous criticism about Krienitz et al.'s (2006) crustal contamination model concerns the possible existence of alteration products (see Lustrino and Wilson, 2007), which may contribute radiogenic Sr in the samples analysed for isotopic compositions, in this study meticulous care was paid to sample selection and preparation, and all but one sample analysed for isotopic compositions were carefully washed in HCl and subsequently in deionised water. With these acid-leaching procedures and Os isotopic constraints, it is revealed that the crustal contribution, although less extensive than the estimations of Krienitz et al. (2006), was important during the evolution of the Miocene Syrian magmas.

2. Geological background

Following the Middle–Late Eocene collision of Arabia and Eurasia, the convergence between the two plates was partially taken up by shortening and thickening within the Arabian continent, especially

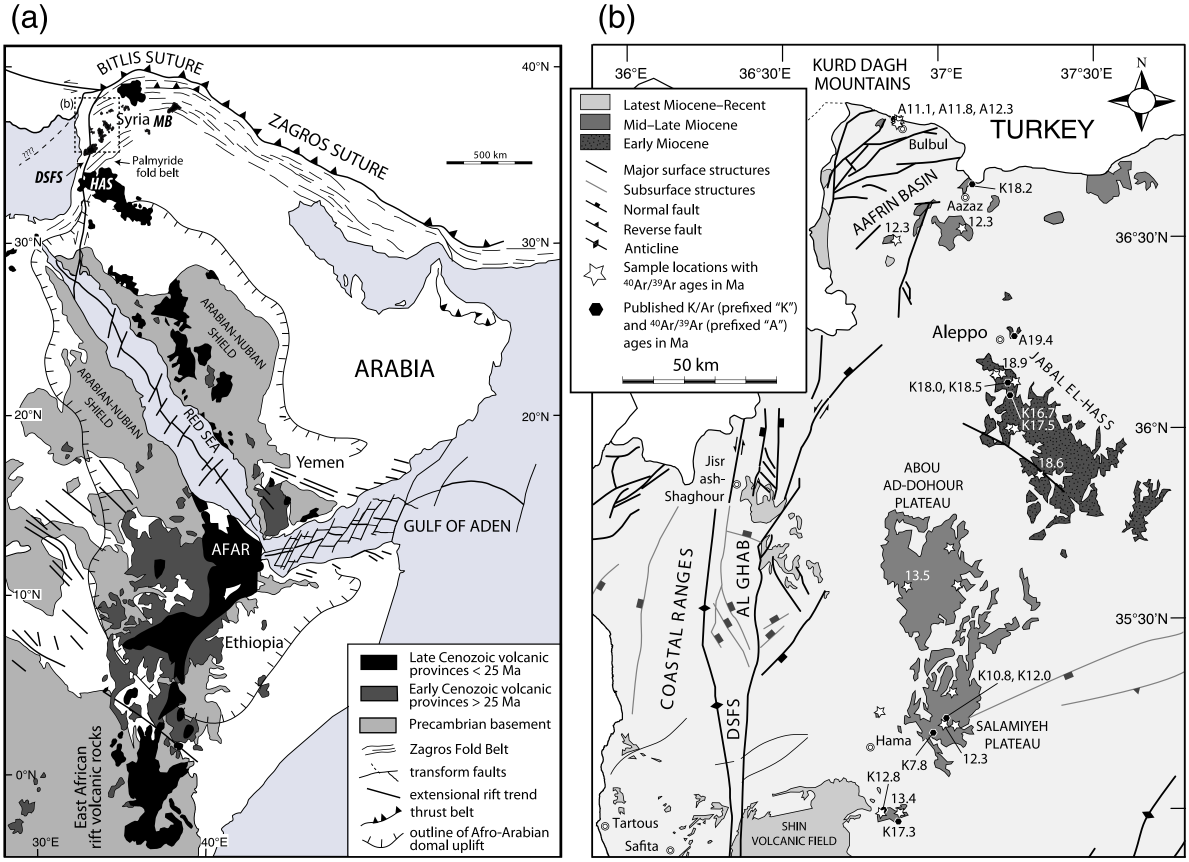

Fig. 1. Simplified geological map of (a) Arabia and northeastern Africa (modified after Davidson et al., 1994) and (b) northwestern Syria highlighting the distribution of Cenozoic volcanic rocks. Dashed box in (a) marks the area shown in (b). Star symbols in (b) mark the sampling points and the numbers adjacent to the stars are ^{40}Ar/^{39}Ar dates in Ma determined in this study (Table 1). Also shown are published K–Ar (Mouty et al., 1992; Sharkov et al., 1994; Trifonov et al., 2011) and ^{40}Ar/^{39}Ar (Krienitz et al., 2009) dates in Ma marked by black hexagonal symbols. Surface and subsurface structures in (b) are based on Brew et al. (2001). *DSFS*, Dead Sea Fault System; *HAS*, Harrat Ash Shamah; *MB*, Mesopotamian Basin.